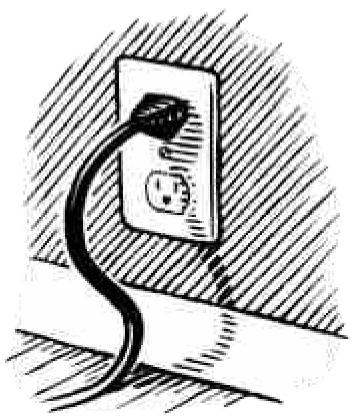
CE443 – Computer Networks

Socket Programming

Networked Applications



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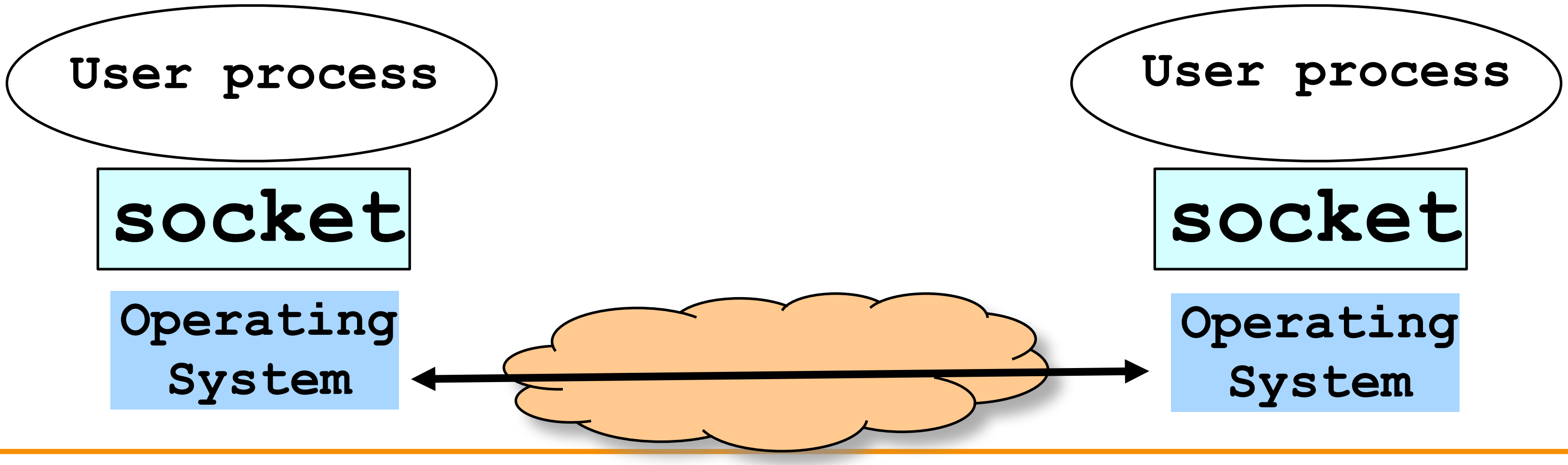
Acknowledgments: Lecture slides are from Computer networks course thought by Jennifer Rexford at Princeton University. When slides are obtained from other sources, a reference will be noted on the bottom of that slide. A full list of references is provided on the last slide.

Socket: End Point of Net. Comm.'s

- Socket as an Application Programming Interface
  - Supports the creation of network applications
- Two ends communicate through a "socket"
  - Sending messages from one **process** to another
  - The transportation details are transparent to the programmer



Delivering the Data: Division of Labor

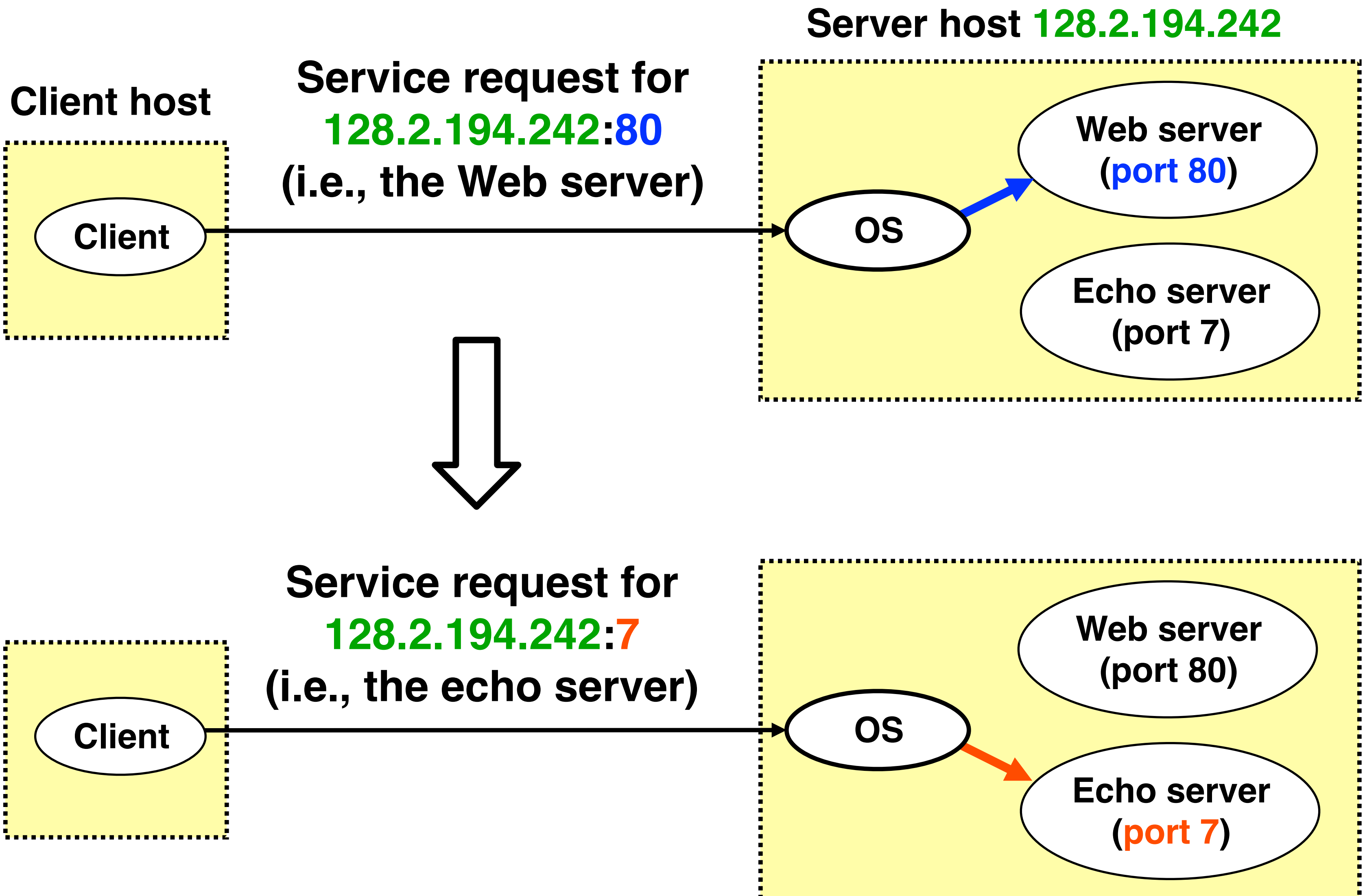
- Application
  - Read data from and write data to the socket
  - Interpret the data (e.g., render a Web page)
- Operating system
  - Deliver data to the destination socket
  - Based on the destination port number

- Network
  - Deliver data packet to the destination host
  - Based on the destination IP address

Identifying the Receiving Process

- Sending process must identify the receiver
  - The receiving end host machine
  - The specific socket in a process on that machine
- Receiving host
  - Destination address that uniquely identifies the host
  - An IPv4 address is a 32-bit quantity
- Receiving socket
  - Host may be running many different processes
  - Destination port that uniquely identifies the socket
  - A port number is a 16-bit quantity

Identifying the Receiving Process



Knowing What Port Number To Use

- Popular applications have well-known ports
  - E.g., port 80 for Web and port 25 for e-mail
  - See http://www.iana.org/assignments/port-numbers
- Well-known vs. ephemeral ports
  - Server has a well-known port (e.g., port 80)
    - Between 0 and 1023
  - Client picks an unused ephemeral (i.e., temporary) port
    - Between 1024 and 65535
- Uniquely identifying the traffic between the hosts
  - Two IP addresses and two port numbers
  - Underlying transport protocol (e.g., TCP or UDP)

Port Numbers are Unique on Each Host

- Port number uniquely identifies the socket
  - Cannot use same port number twice with same address
  - Otherwise, the OS can't demultiplex packets correctly
- Operating system enforces uniqueness
  - OS keeps track of which port numbers are in use
  - Doesn't let the second program use the port number
- Example: two Web servers running on a machine
  - They cannot both use port "80", the standard port #
  - So, the second one might use a non-standard port #
  - E.g., http://www.cnn.com:8080

UNIX Socket API

UNIX Socket API

- Socket interface
  - Originally provided in Berkeley UNIX
  - Later adopted by all popular operating systems
  - Simplifies porting applications to different OSes (even to the Windows!)
- In UNIX, everything is like a file
  - All input is like reading a file
  - All output is like writing a file
  - File is represented by an integer file descriptor
- API implemented as system calls
  - E.g., connect, read, write, close, …

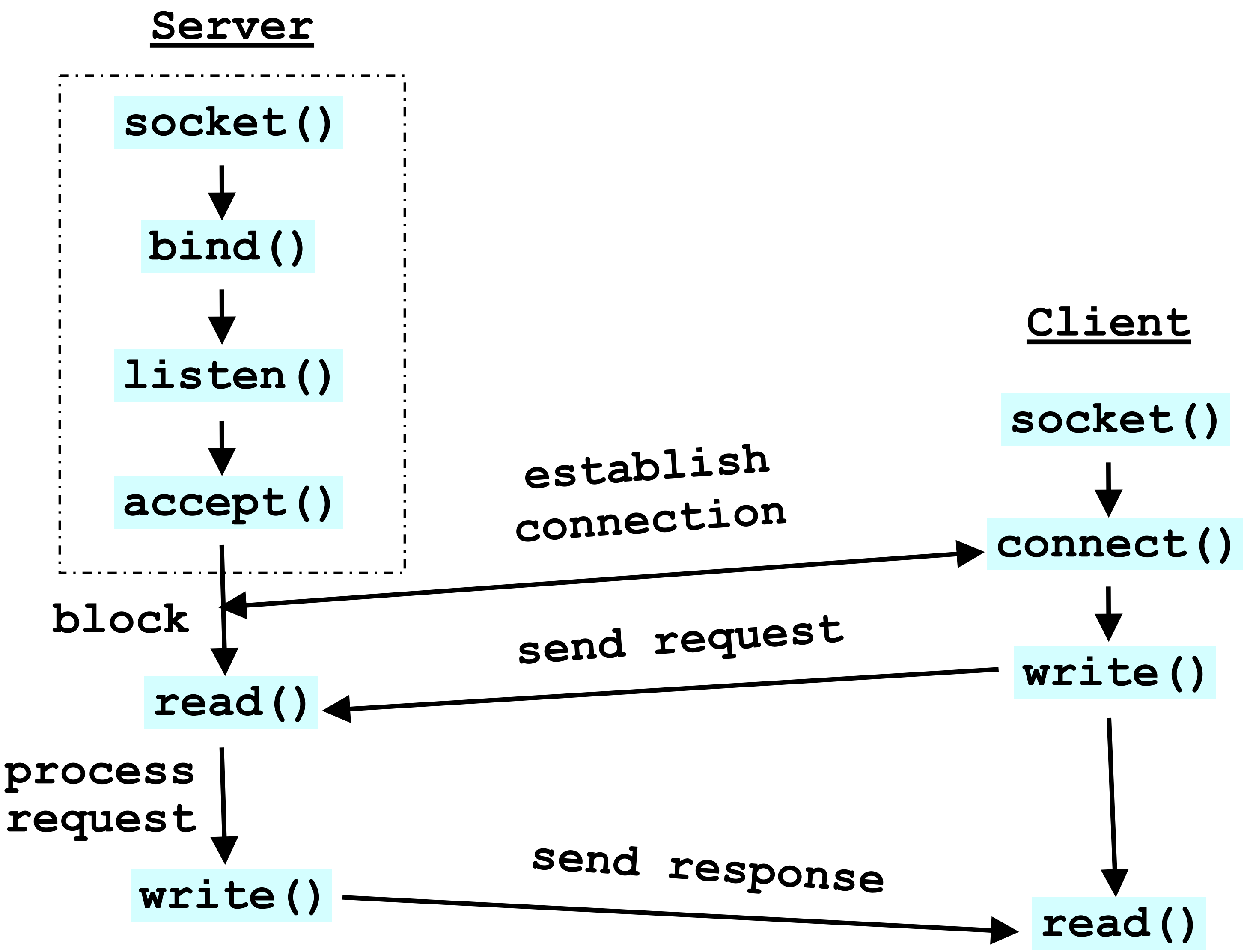
Typical Client Program

- Prepare to communicate
  - Create a socket
  - Determine server address and port number
  - Initiate the connection to the server
- Exchange data with the server
  - Write data to the socket
  - Read data from the socket
  - Do stuff with the data (e.g., render a Web page)
- Close the socket

Typical Server Program

- Prepare to communicate
  - Create a socket
  - Associate local address and port with the socket
- Wait to hear from a client (passive open)
  - Indicate how many clients-in-waiting to permit
  - Accept an incoming connection from a client
- Exchange data with the client over new socket
  - Receive data from the socket
  - Do stuff to handle the request (e.g., get a file)
  - Send data to the socket
  - Close the socket
- Repeat with the next connection request

Putting it All Together



Wanna See Real Clients and Servers?

- Apache Web server
  - Open source server first released in 1995
  - Name derives from “a patchy server” ;-)
  - Software available online at http://www.apache.org
- Mozilla Web browser
  - http://www.mozilla.org/developer/
- Sendmail
  - http://www.sendmail.org/
- BIND Domain Name System (Datagram)
  - Client resolver and DNS server
  - http://www.isc.org/index.pl?/sw/bind/
- …

Wanna to have fun? Okay…

Client Programming

Client Creating a Socket: socket()

int **socket**(int **domain**, int **type**, int **protocol**)

- Operation to create a socket
  - Returns a descriptor (or handle) for the socket
  - Originally designed to support any protocol suite
- Domain: protocol family
  - PF_INET for the Internet
- Type: semantics of the communication
  - SOCK_STREAM: reliable byte stream
  - SOCK_DGRAM: message-oriented service
- Protocol: specific protocol
  - UNSPEC: unspecified
  - (PF_INET and SOCK_STREAM already implies TCP)

Client: Learning Server Address/Port

- Server typically known by name and service
  - "www.google.com" and "http"
- Which must be translated into IP address and port #
- Translating the server's name to an address
  - int **getaddrinfo**(const char *node, const char *service, const struct addrinfo *hints, struct addrinfo **res);
  - void **freeaddrinfo**(struct addrinfo *res);
  - int **getnameinfo**(const struct sockaddr *sa, socklen_t salen,char *host, size_t hostlen, char *serv, size_t servlen, int flags);
- Check Linux Man pages for details

Client: Learning Server Address/Port

- struct addrinfo {
    int ai_flags;
    int ai_family;
    int ai_socktype;
    int ai_protocol;
    socklen_t ai_addrlen;
    struct sockaddr *ai_addr;
    char *ai_canonname;
    struct addrinfo *ai_next;
  };

IP Address Data Structures

```
include <netinet/in.h>

// All pointers to socket address structures are often cast to pointers
// to this type before use in various functions and system calls:

struct sockaddr {
    unsigned short    sa_family;    // address family, AF_xxx
    char              sa_data[14];  // 14 bytes of protocol address
};


// IPv4 AF_INET sockets:

struct sockaddr_in {
    short            sin_family;   // e.g. AF_INET, AF_INET6
    unsigned short   sin_port;     // e.g. htons(3490)
    struct in_addr   sin_addr;     // see struct in_addr, below
    char             sin_zero[8];  // zero this if you want to
};

struct in_addr {
    unsigned long s_addr;          // load with inet_pton()
};
```

Client: Connecting Socket to the Server

int **connect**(int **sockfd**, struct sockaddr ***server_address**, socketlen_t **addrlen**)

- Client contacts the server to establish connection
  - Associate the socket with the server address/port
  - Acquire a local port number (assigned by the OS)
  - Request connection to server, who will hopefully accept
- Establishing the connection
  - Arguments: socket descriptor, server address, and address size
  - Returns 0 on success, and -1 if an error occurs

Client: Sending and Receiving Data

- Sending data

  ssize_t **write**(int **sockfd**, void ***buf**, size_t **len**)

  – Arguments: socket descriptor, pointer to buffer of data to send, and length of the buffer
  – Returns the number of characters written, and -1 on error

- Receiving data

  ssize_t **read**(int **sockfd**, void ***buf**, size_t **len**)

  – Arguments: socket descriptor, pointer to buffer to place the data, size of the buffer
  – Returns the number of characters read (where 0 implies "end of file"), and -1 on error

- Closing the socket

  int **close**(int **sockfd**)

Not enough fun? Okay… face a headache!

Server Programming

Servers Differ From Clients

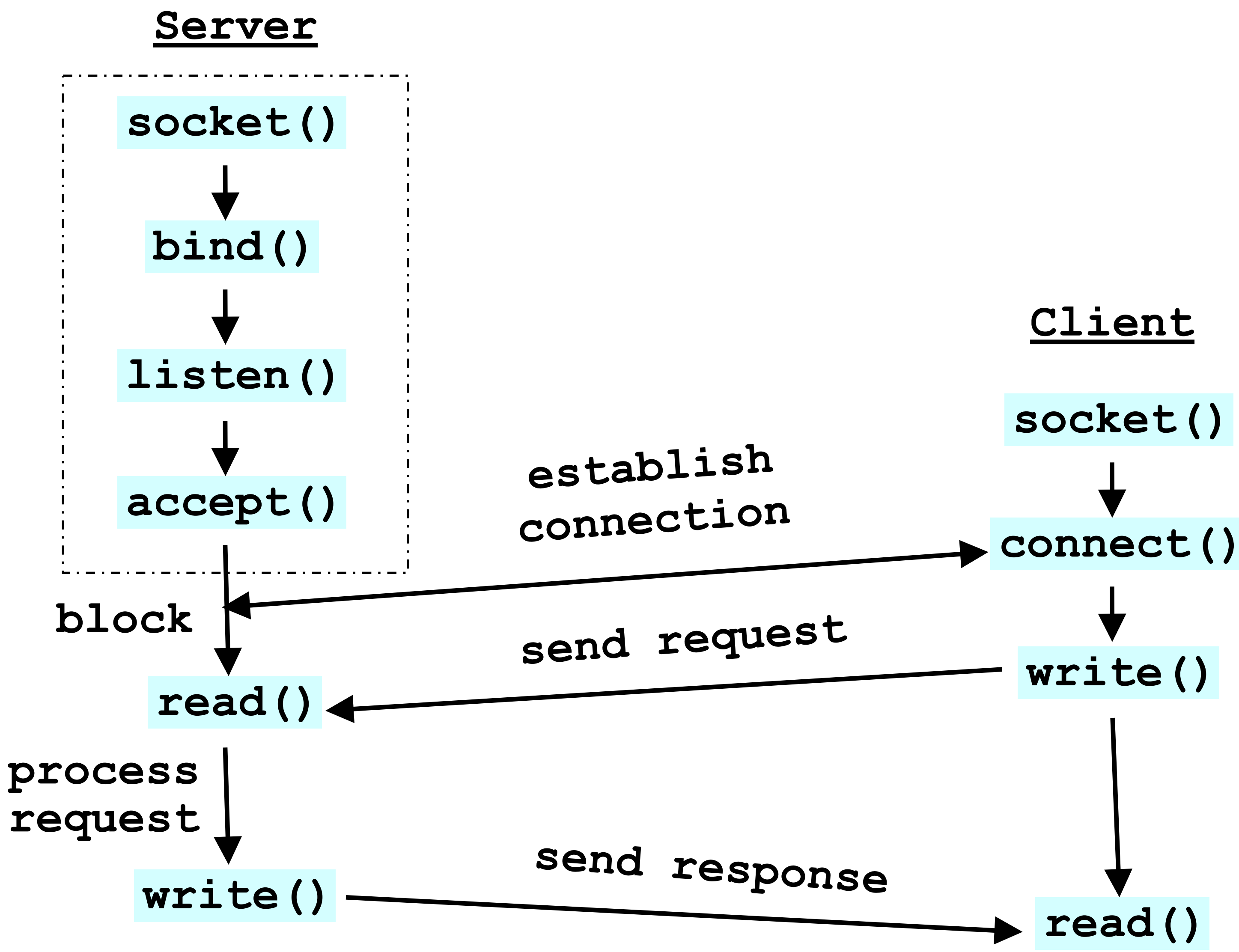
- Passive open
  - Prepare to accept connections
  - … but don't actually establish
  - … until hearing from a client

- Hearing from multiple clients
  - Allowing a backlog of waiting clients
  - ... in case several try to communicate at once
- Create a socket for each client
  - Upon accepting a new client
  - … create a *new* socket for the communication

Remember: Typical Server Program

- Prepare to communicate
  - Create a socket
  - Associate local address and port with the socket
- Wait to hear from a client (passive open)
  - Indicate how many clients-in-waiting to permit
  - Accept an incoming connection from a client
- Exchange data with the client over new socket
  - Receive data from the socket
  - Do stuff to handle the request (e.g., get a file)
  - Send data to the socket
  - Close the socket
- Repeat with the next connection request

Remember: The Big Picture



Server: Server Preparing its Socket

- Server creates a socket and binds address/port
  - Server creates a socket, just like the client does
  - Server associates the socket with the port number (and hopefully no other process is already using it!)
- Create a socket

  int **socket**(int **domain**, int **type**, int **protocol**)
- Bind socket to the local address and port number

  int **bind**(int **sockfd**, struct sockaddr ***my_addr**, socklen_t **addrlen**)
  - Arguments: socket descriptor, server address, address length
  - Returns 0 on success, and -1 if an error occurs

Server: Allowing Clients to Wait

- Many client requests may arrive
  - Server cannot handle them all at the same time
  - Server could reject the requests, or let them wait
  - Define how many connections can be pending: backlog
- Wait for clients

  int **listen**(int **sockfd**, int **backlog**)
  - Arguments: socket descriptor and acceptable backlog
  - Returns a 0 on success, and -1 on error
- What if too many clients arrive?
  - Some requests don't get through
  - The Internet makes no promises…
  - And the client can always try again

Server: Accepting Client Connection

- Now all the server can do is wait…
  - Waits for connection request to arrive
  - Blocking until the request arrives
  - And then accepting the new request
- Accept a new connection from a client

  int **accept**(int **sockfd**, struct sockaddr ***addr**, socketlen_t ***addrlen**)

  - Arguments: socket descriptor, structure that will provide client address and port, and length of the structure
  - Returns descriptor for a new socket for this connection

Server: One Request at a Time?

- Serializing requests is inefficient
  - Server can process just one request at a time
  - All other clients must wait until previous one is done
- May need to time share the server machine
  - Alternate between servicing different requests
    - E.g. use multi-threading
  - Or, start a new process to handle each request
    - Allow the operating system to share the CPU across processes
  - Or, some hybrid of these two approaches

Client and Server: Cleaning House

- Once the connection is open
  - Both sides and read and write
  - Two unidirectional streams of data
  - In practice, client writes first, and server reads
  - … then server writes, and client reads, and so on
- Closing down the connection
  - Either side can close the connection
  - … using the close() system call
- What about the data still “in flight”
  - Data in flight still reaches the other end
  - So, server can close() before client finishing reading

The Problem of Interoperability

Byte Order

- Hosts differ in how they store data
  - E.g., four-byte number (byte3, byte2, byte1, byte0)
- Little endian ("little end comes first") ← Intel PCs!!!
  - Low-order byte stored at the lowest memory location
  - Byte0, byte1, byte2, byte3
- Big endian ("big end comes first")
  - High-order byte stored at lowest memory location
  - Byte3, byte2, byte1, byte 0
- Makes it more difficult to write portable code
  - Client may be big or little endian machine
  - Server may be big or little endian machine

IP is Big Endian

- But, what byte order is used "on the wire"
  - That is, what do the network protocol use?
- The Internet Protocols picked one convention
  - IP is big endian (aka "network byte order")
- Writing portable code require conversion
  - Use htons() and htonl() to convert to network byte order
  - Use ntohs() and ntohl() to convert to host order
- Hides details of what kind of machine you're on
  - Use the system calls when sending/receiving data structures longer than one byte

Why Can't Sockets Hide These Details?

- Dealing with endian differences is tedious
  - Couldn't the socket implementation deal with this
  - … by swapping the bytes as needed?
- No, swapping depends on the data type
  - Two-byte short int: (byte 1, byte 0) vs. (byte 0, byte 1)
  - Four-byte long int: (byte 3, byte 2, byte 1, byte 0) vs. (byte 0, byte 1, byte 2, byte 3)
  - String of one-byte charters: (char 0, char 1, char 2, …) in both cases
- Socket layer doesn't know the data types
  - Sees the data as simply a buffer pointer and a length
  - Doesn't have enough information to do the swapping

The Web as an Example Application

The Web: URL, HTML, and HTTP

- Uniform Resource Locator (URL)
  - A pointer to a "black box" that accepts request methods
  - Formatted string with protocol (e.g., http), server name (e.g., www.cnn.com), and resource name (coolpic.jpg)
- HyperText Markup Language (HTML)
  - Representation of hyptertext documents in ASCII format
  - Format text, reference images, embed hyperlinks
  - Interpreted by Web browsers when rendering a page
- HyperText Transfer Protocol (HTTP)
  - Client-server protocol for transferring resources
  - Client sends request and server sends response

Example: HyperText Transfer Protocol

```
GET /courses/archive/spring08/cos461/ HTTP/1.1
Host: www.cs.princeton.edu
User-Agent: Mozilla/4.03
<CRLF>
```

Request

Response

```
HTTP/1.1 200 OK
Date: Mon, 4 Feb 2008 13:09:03 GMT
Server: Netscape-Enterprise/3.5.1
Content-Type: text/plain
Last-Modified: Mon, 4 Feb  2008 11:12:23 GMT
Content-Length: 21
<CRLF>
Site under construction
```

In Fact, Try This at a UNIX Prompt…

```
labpc: telnet www.cnn.com 80
GET /index.html HTTP/1.1
Host: www.cnn.com
<CRLF>
```

And you'll see the response…

Web Server

- Web site vs. Web server
  - Web site: collections of Web pages associated with a particular host name
  - Web server: program that satisfies client requests for Web resources
- Handling a client request
  - Accept the socket
  - Read and parse the HTTP request message
  - Translate the URL to a filename
  - Determine whether the request is authorized
  - Generate and transmit the response